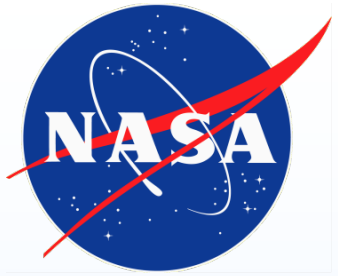

Single-Event Threats for Diodes – It's Not Just Schottky Diodes

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Acronyms

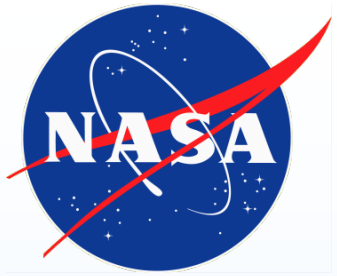
- DUT – Device Under Test
- GSFC – Goddard Space Flight Center
- I_F – Forward Current
- I_R – Reverse Current
- RF – Radio Frequency
- SBD – Super Barrier Diode
- SEE – Single-Event Effects
- V_R – Reverse Voltage
- V_F – Forward Voltage

Introduction

- Since 2011, GSFC has been investigating destructive SEEs in Schottky diodes
  - We have recommended a 50% V_R derating for operation in heavy-ion environments

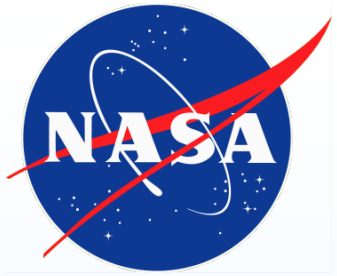
- During this investigation, several super barrier diodes were also irradiated and experienced failures identical to the Schottky diodes that were tested
  - In retrospect, this is not totally unexpected as SBDs also have a Schottky junction, but also employs an insulating layer between the metal and semiconductor material
  - However, this led us to question whether the failure mechanism is limited to diodes with Schottky junctions or if it exists in other diode types as well

Test Facilities and Technique



- All parts were tested at LBNL's 88-inch cyclotron with 1233 MeV Xe (LET = 58.8 MeV-cm^2/mg)
- All diodes were irradiated under reverse bias and at room temperature
- After each beam run, V_F, V_R, I_F and I_R were measured
- Because a 50% derating has been found to be sufficient for Schottky diodes, that was the initial test voltage
- A minimum of 3 DUTs per part type were tested

Parts Tested



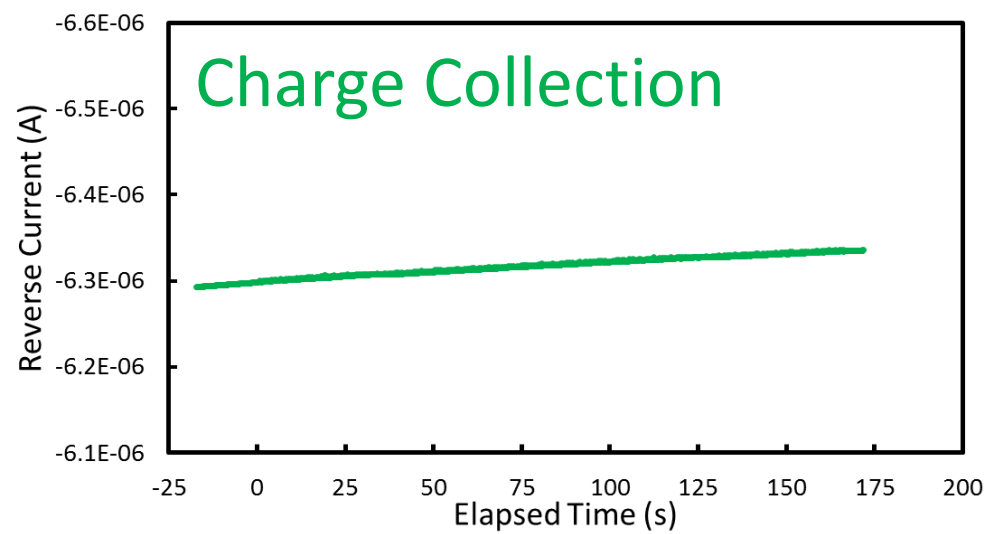
- 30 diodes from 10 manufacturers
- 5 diode types: avalanche, RF PiN, super barrier, switching, and Zener
- Reverse voltages range from 35 V to 200 V
- Forward currents (per diode) from 2 mA to 10 A
- Within the manufacturers, high temperature, high forward voltage lines are compared to low temperature, low forward voltage and low barrier height lines

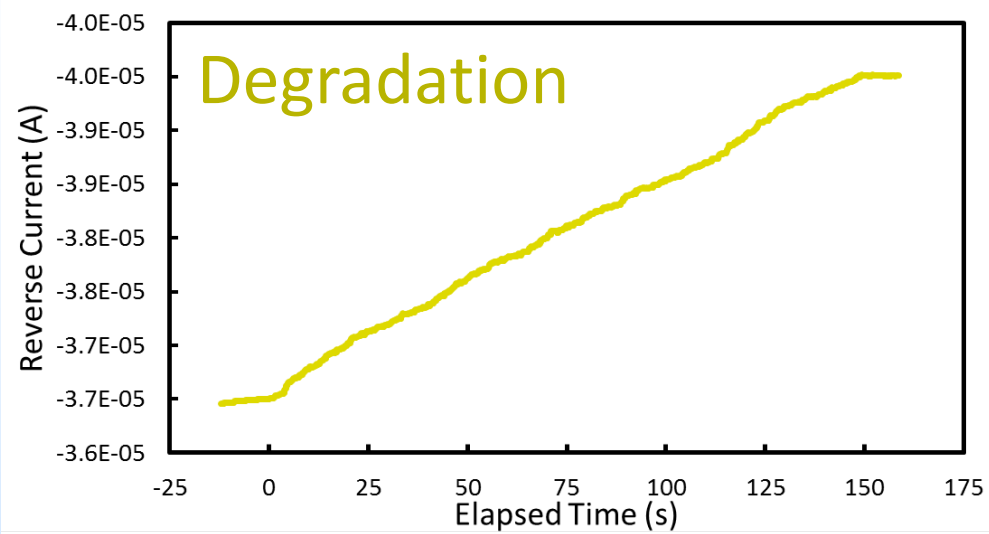
Diodes Tested

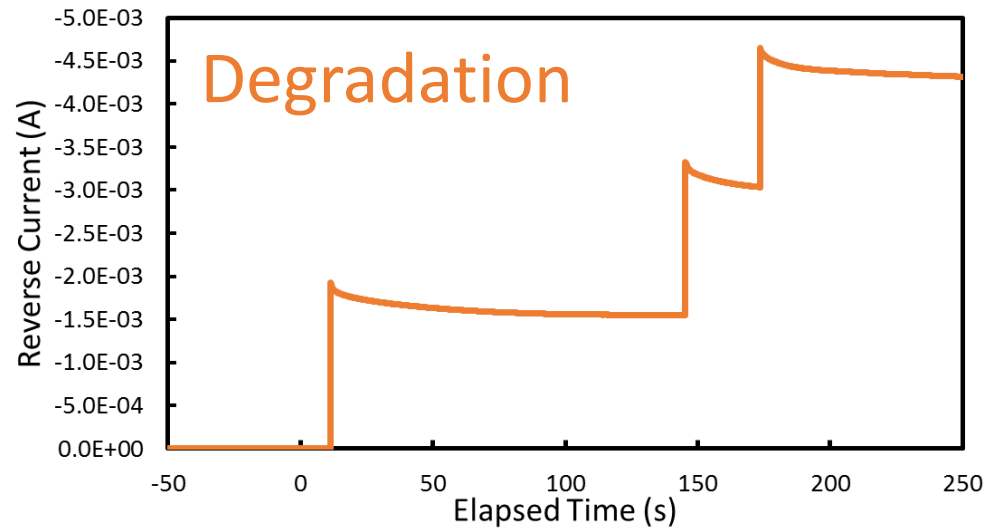
Diode Type	Manufacturer	Part Number	Reverse Voltage	Forward Current
Avalanche	NXP Semi	BAS29,215	90 V	200 mA
Super Barrier	Diodes Inc	SBR1U200P1-7	200 V	1 A
Super Barrier	Diodes Inc	SBR1045D1-13	45 V	10 A
Super Barrier	Diodes Inc	SBR160S23-7	60 V	900 mA
Super Barrier	Diodes Inc	SBRT10U60D1-13	60 V	10 A
Zener	Diodes Inc	BZX84C47-7-F	47 V	10 mA
Zener	NXP Semi	BZX84-B47,215	47 V	10 mA
Zener	NXP Semi	BZX84-C56,215	56 V	10 mA
Zener	NXP Semi	BZX84-C68,215	68 V	10 mA
Zener	NXP Semi	BZX84-A75,215	75 V	10 mA
Zener	On Semi	BZX84C56LT1G	56 V	10 mA
Zener	On Semi	BZX84C68LT1G	68 V	10 mA
Zener	On Semi	BZX84C75LT1G	75 V	10 mA
Zener	Vishay	BZX84C56-E3-08	56 V	2 mA

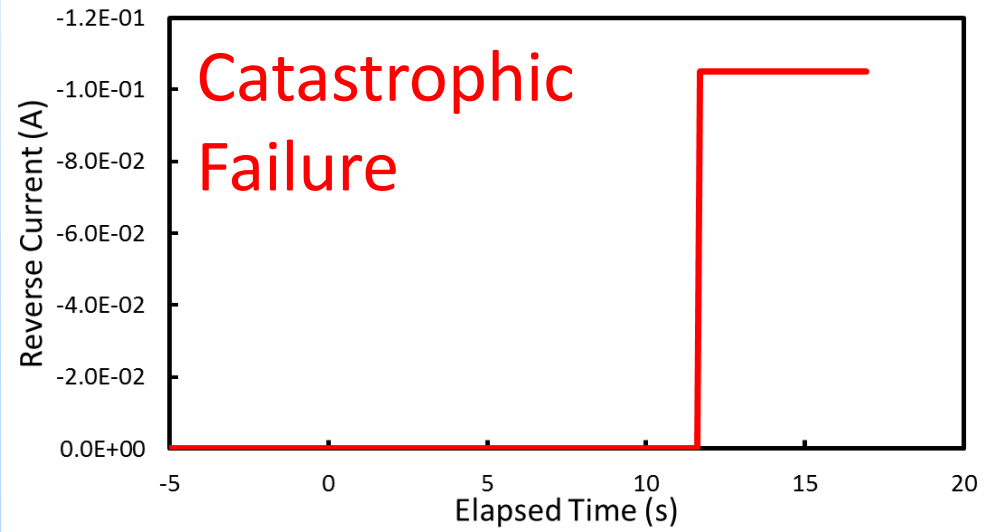
Diode Type	Manufacturer	Part Number	Reverse Voltage	Forward Current
PiN	Broadcom	HSMP-3810-TR1G	100 V	1 A
PiN	Infineon	BAR64-05 E6327	150 V	100 mA
PiN	M/A-COM	MA4P7455CK-287T	100 V	150 mA
PiN	NXP Semi	BAP64-05,215	175 V	100 mA
PiN	NXP Semi	BAT18,215	35 V	100 mA
PiN	NXP Semi	BAP50-05,215	50 V	50 mA
PiN	Skyworks	SMP1307-004LF	200 V	100 mA
Switching	Central Semi	CMPD2003 TR	200 V	200 mA
Switching	Diodes Inc	BAS21-7-F	200 V	200 mA
Switching	Fairchild	MMBD914	100 V	200 mA
Switching	Fairchild	MMBD1501A	200 V	200 mA
Switching	NXP Semi	BAS16,215	100 V	215 mA
Switching	NXP Semi	BAS21,215	200 V	200 mA
Switching	On Semi	MMBD914LT1G	100 V	200 mA
Switching	On Semi	BAS20LT1G	200 V	200 mA
Switching	Vishay	BAS21-E3-08	200 V	200 mA

Observed Radiation Responses

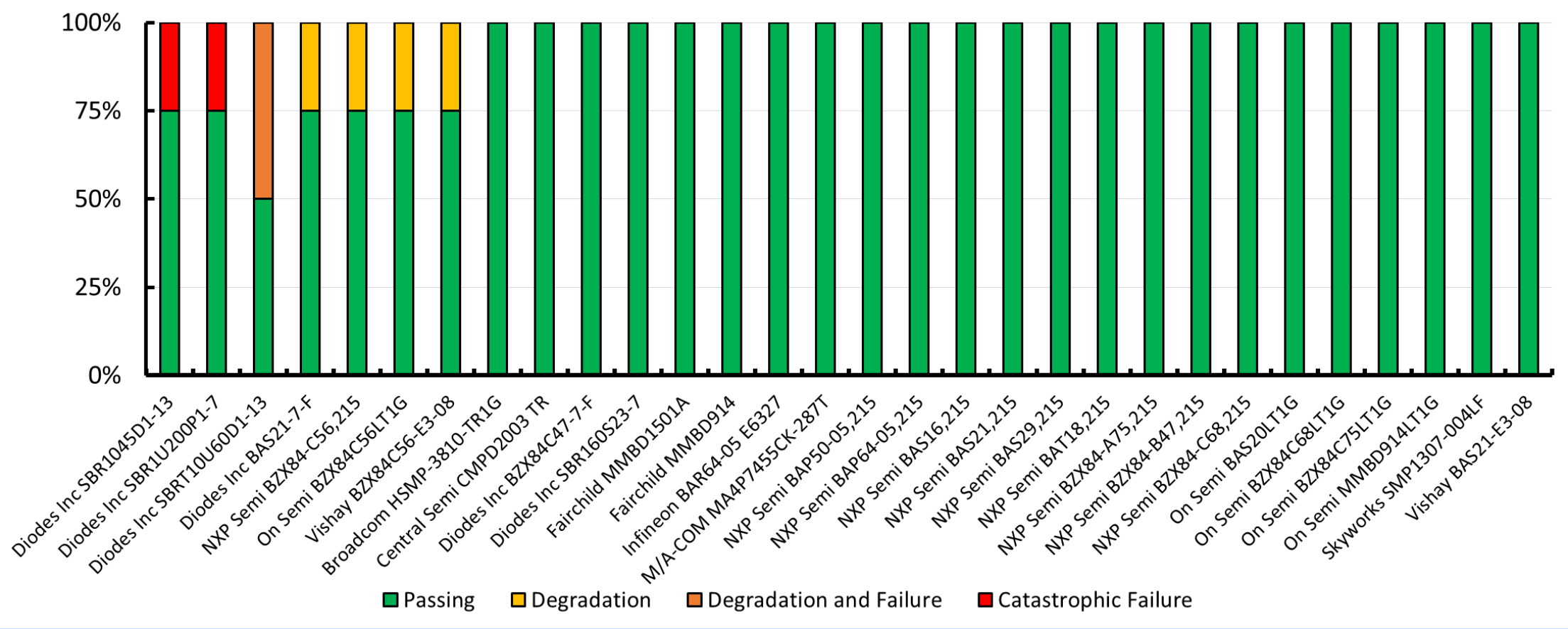








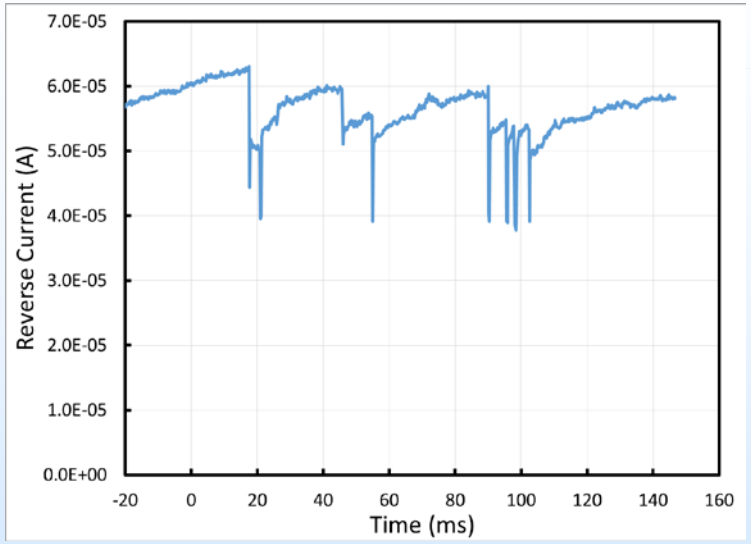
Results

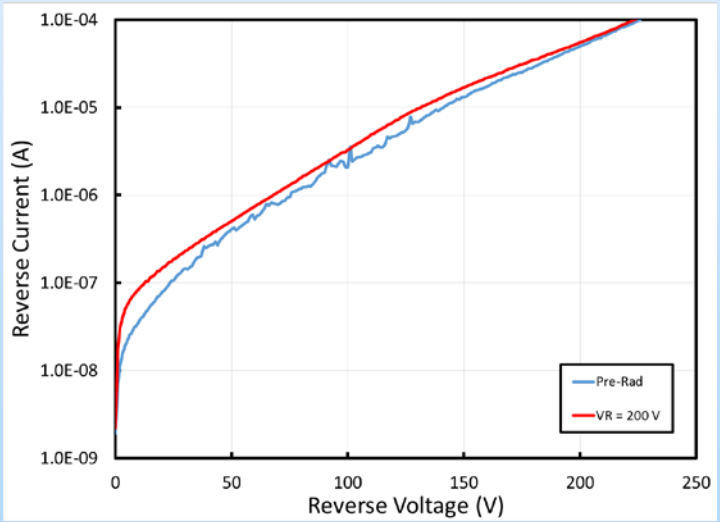

100%
75%
50%
25%
0%
Diodes Inc SBR1045D1-13
Diodes Inc SBR1U200P1-7
Diodes Inc SBRT10U60D1-13
Diodes Inc BAS21-7-F
NXP Semi BZX84-C56,215
On Semi BZX84C56LT1G
Vishay BZX84C56-E3-08
Broadcom HSMP-3810-TR1G
Central Semi CMPD2003 TR
Diodes Inc BZX84C47-7-F
Diodes Inc SBR160S23-7
Fairchild MMBD1501A
Fairchild MMBD914
Infineon BAR64-05 E6327
M/A-COM MA4P7455CK-287T
NXP Semi BAP50-05,215
NXP Semi BAP64-05,215
NXP Semi BAS16,215
NXP Semi BAS21,215
NXP Semi BAS29,215
NXP Semi BAT18,215
NXP Semi BZX84-A75,215
NXP Semi BZX84-B47,215
NXP Semi BZX84-C68,215
On Semi BAS20LT1G
On Semi BZX84C68LT1G
On Semi BZX84C75LT1G
On Semi MMBD914LT1G
Skyworks SMP1307-004LF
Vishay BAS21-E3-08
Passing
Degradation
Degradation and Failure
Catastrophic Failure

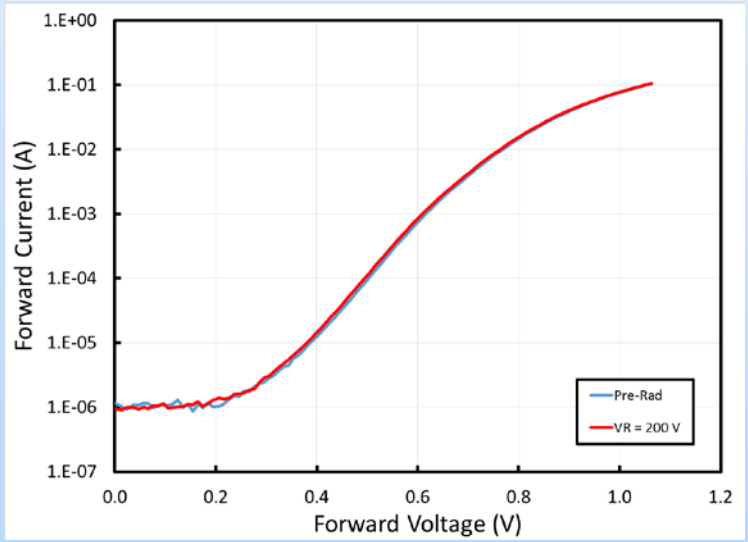
Diodes, Inc. BAS21-7-F Switching Diode

- Small changes in the reverse current were observed during the runs in which these parts were biased at the full-rated 200-V reverse voltage

- Small changes in the I_R-V_R and I_F-V_F plots were observed after the runs
  - How these changes effect the long-term reliability of the parts is unknown







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Results

- Previously tested SBDs were high-power (V_R = 300 V and I_R = 10 and 20 A), but these SBDs were lower power and most still experienced catastrophic failure
  - The exception was an SBD with V_R = 60 V and IR = 900 mA
  - The other SBD ratings were: V_R = 200 V and I_R = 1 A, V_R = 45 V and I_R = 10 A, and V_R = 60 V and I_R = 10 A, which are comparable power output to standard Schottky diodes

- All three 56 V Zener diodes experienced degradation (from three different manufacturers), but no other Zeners did

Conclusions

- Only diodes with a Schottky junction appear to experience catastrophic failure under the conditions tested
- Degradation was observed in an RF switching diode and several Zener diodes
  - While all measured electrical parameters remained within specification after degradation was observed, the long-term reliability of these parts is unknown
- Degradation and failure mechanisms are not limited to power devices
- NSREC 2017 poster presentation will show detailed failure analysis, which seems to indicate there are two different failure mechanisms